Lecture 12

November 20, 2018

Lab 6

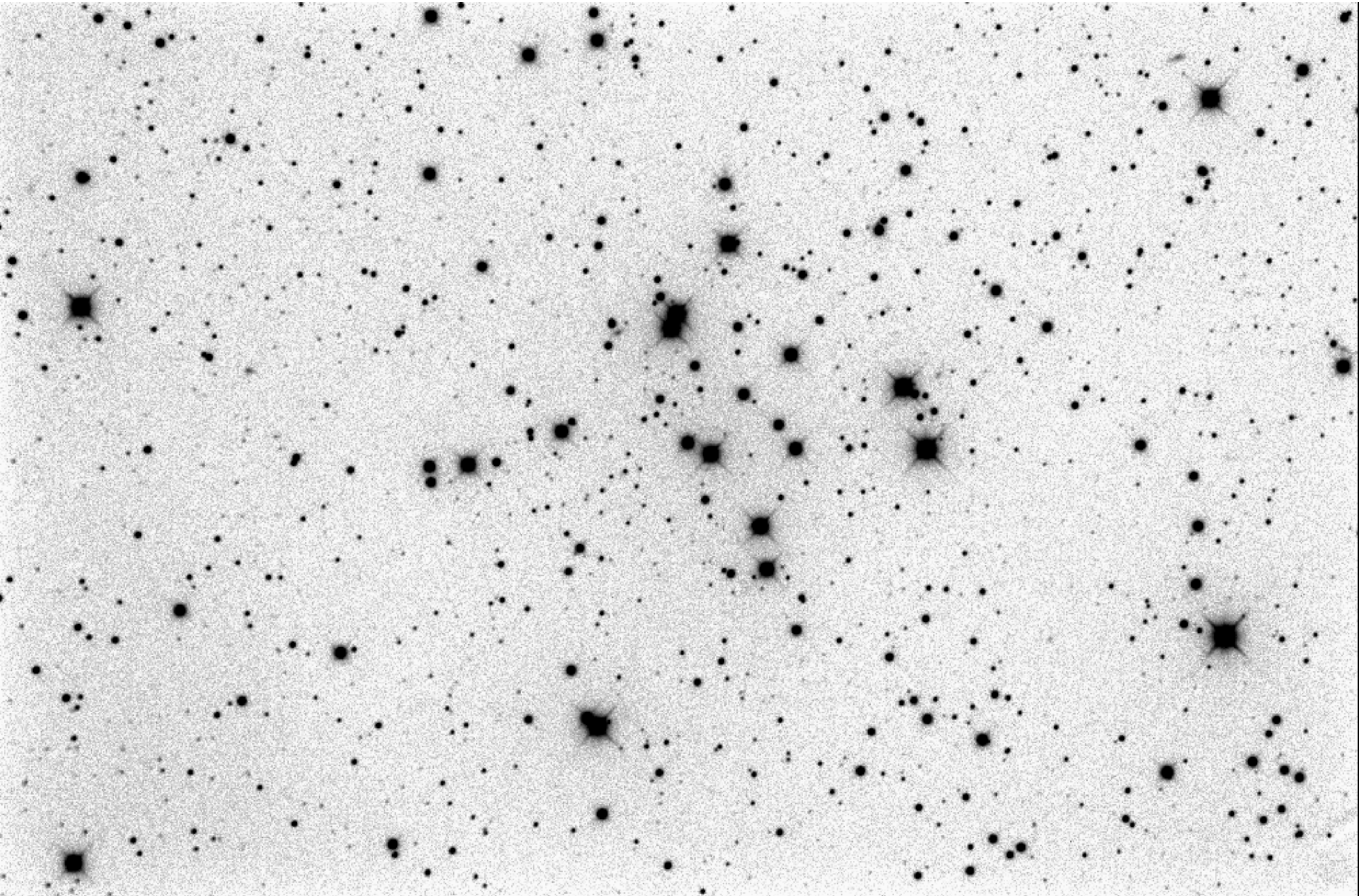
News

- Lab 4
  - Handed back next week (I hope).
- Lab 6 (Color-Magnitude Diagram)
  - Observing completed; you have been assigned data if you were not able to observe.
  - Due: instrumental color-magnitude diagram: email it to me by tomorrow (or whenever you finish it). Whole lab due November 29.

Lab 6: Color-Magnitude Diagram

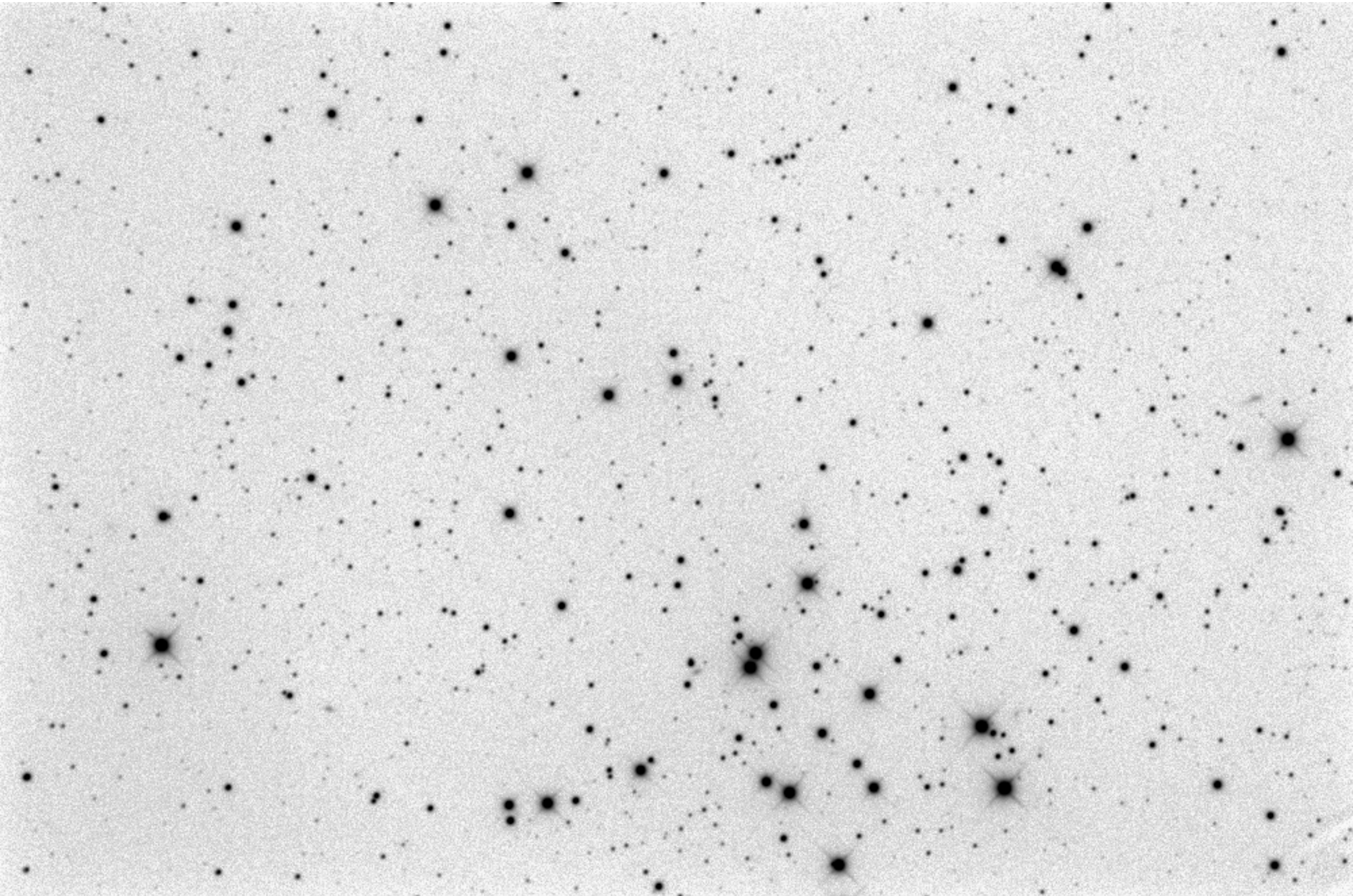
- Target is the open cluster M34.
  - CMD can determine the cluster distance and age.
- Will again perform differential photometry by using stars in the field with known standard magnitudes.
  - So the observations can be taken through thin scattered clouds.
- Will observe in both the B and V filter to get stellar colors, $B-V$.
  - Color measures stellar surface temperature.

M34 V 300 sec



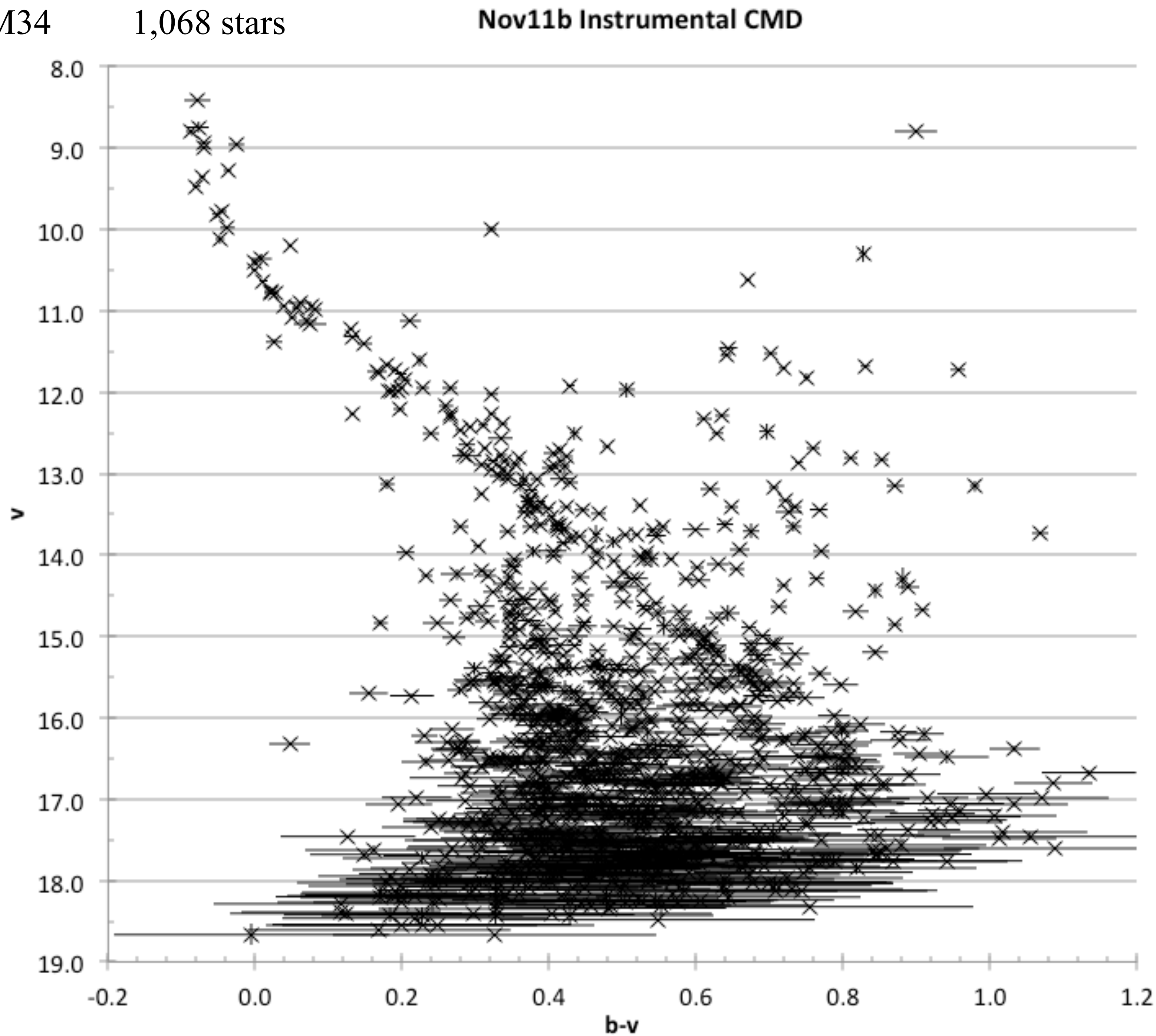
One field approximately centered on M34.

M34a V 300 sec

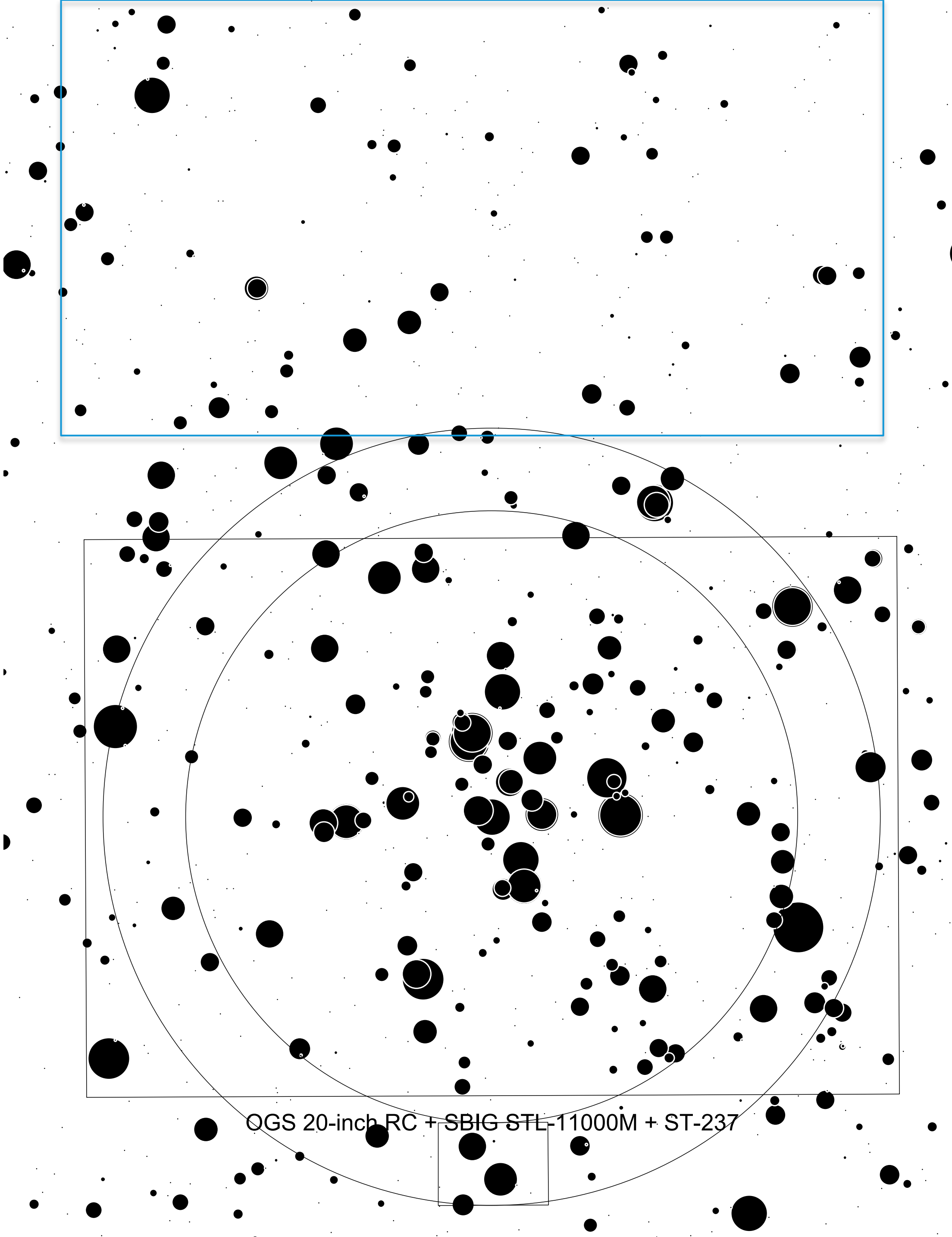


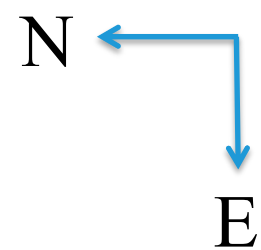
A field with the center offset.

M34 1,068 stars



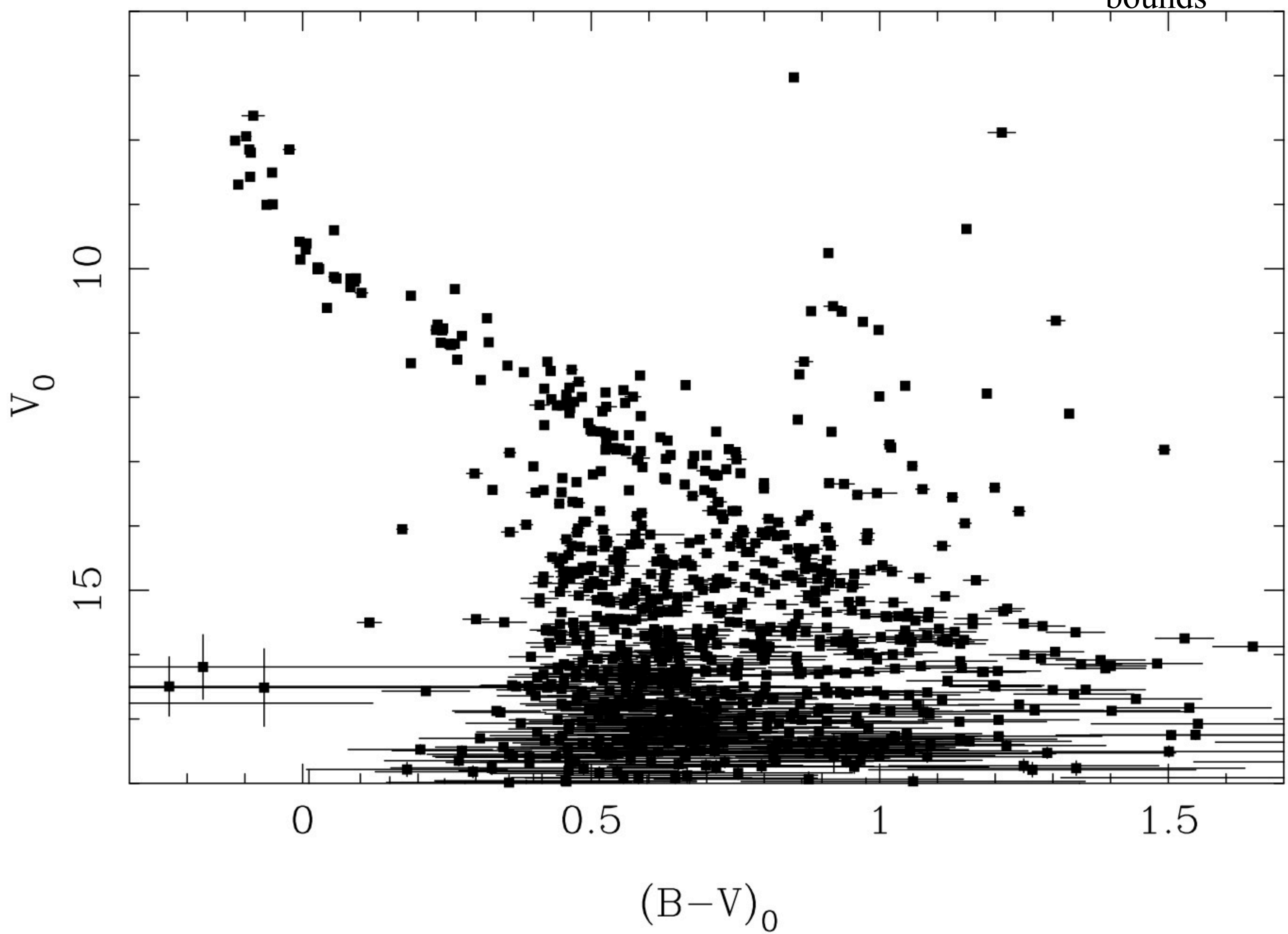
Location of the offset field.



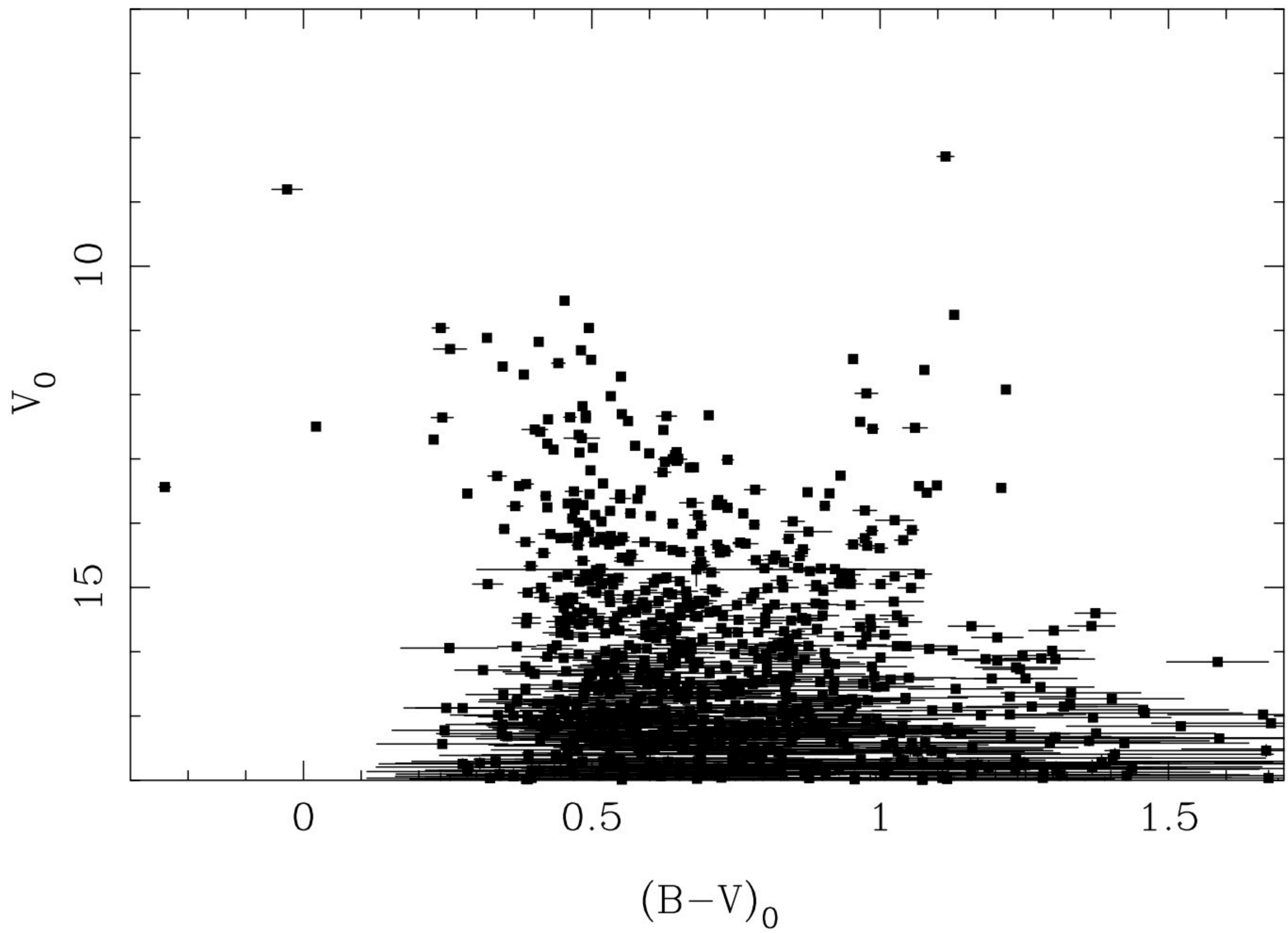


M34

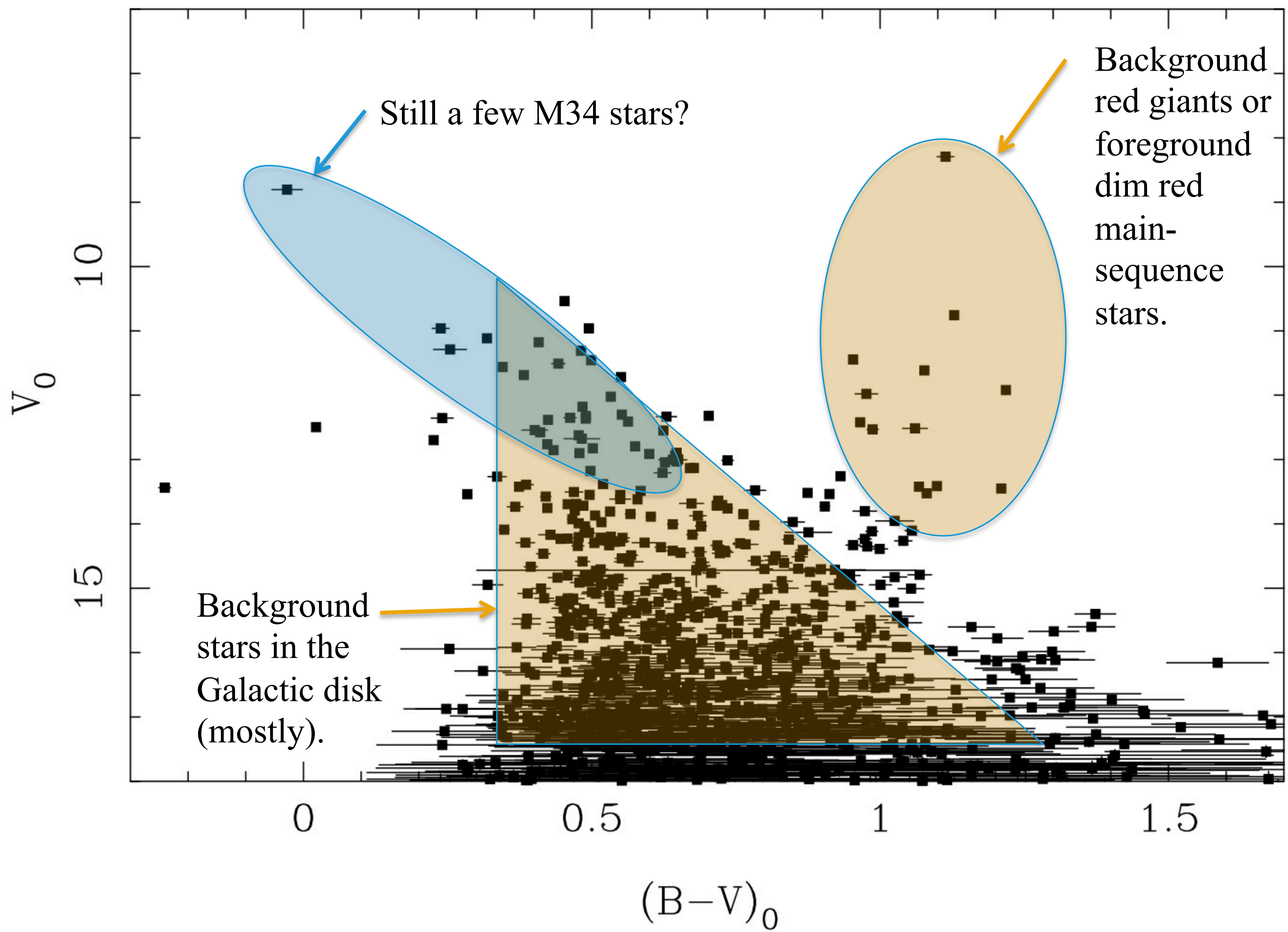
907 stars; some are outside plot bounds

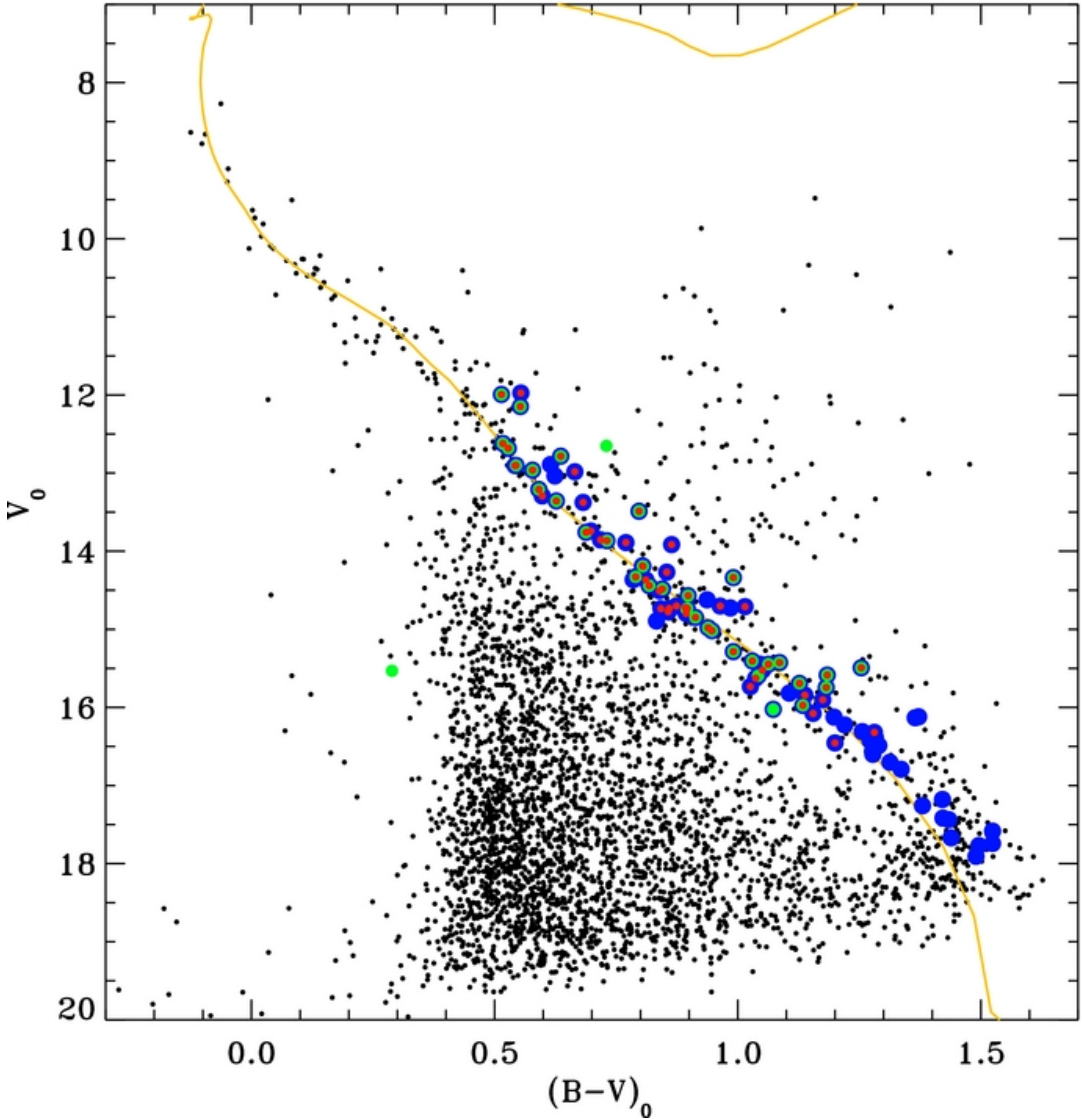


M34 Offset Field



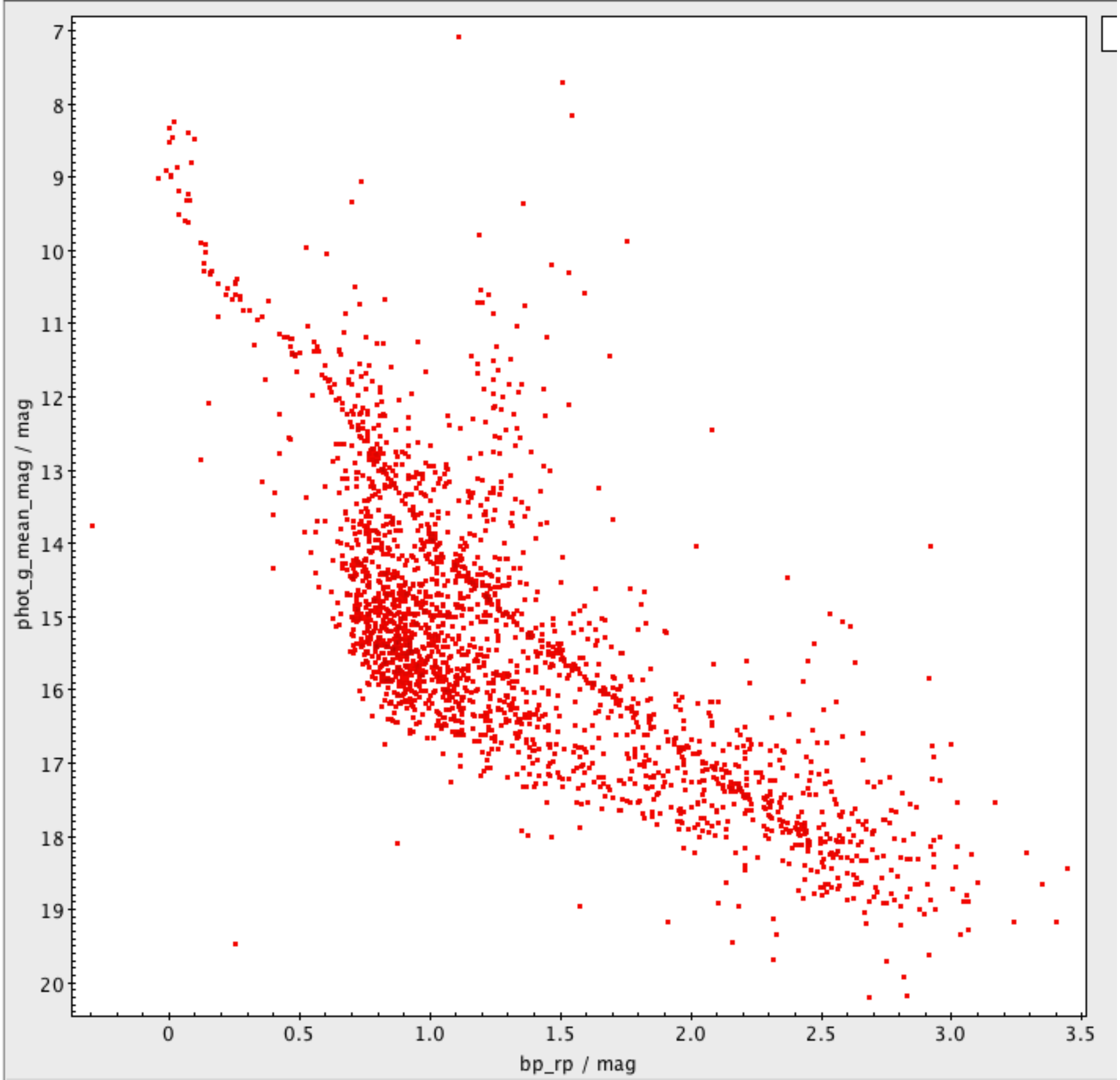
M34 Offset Field



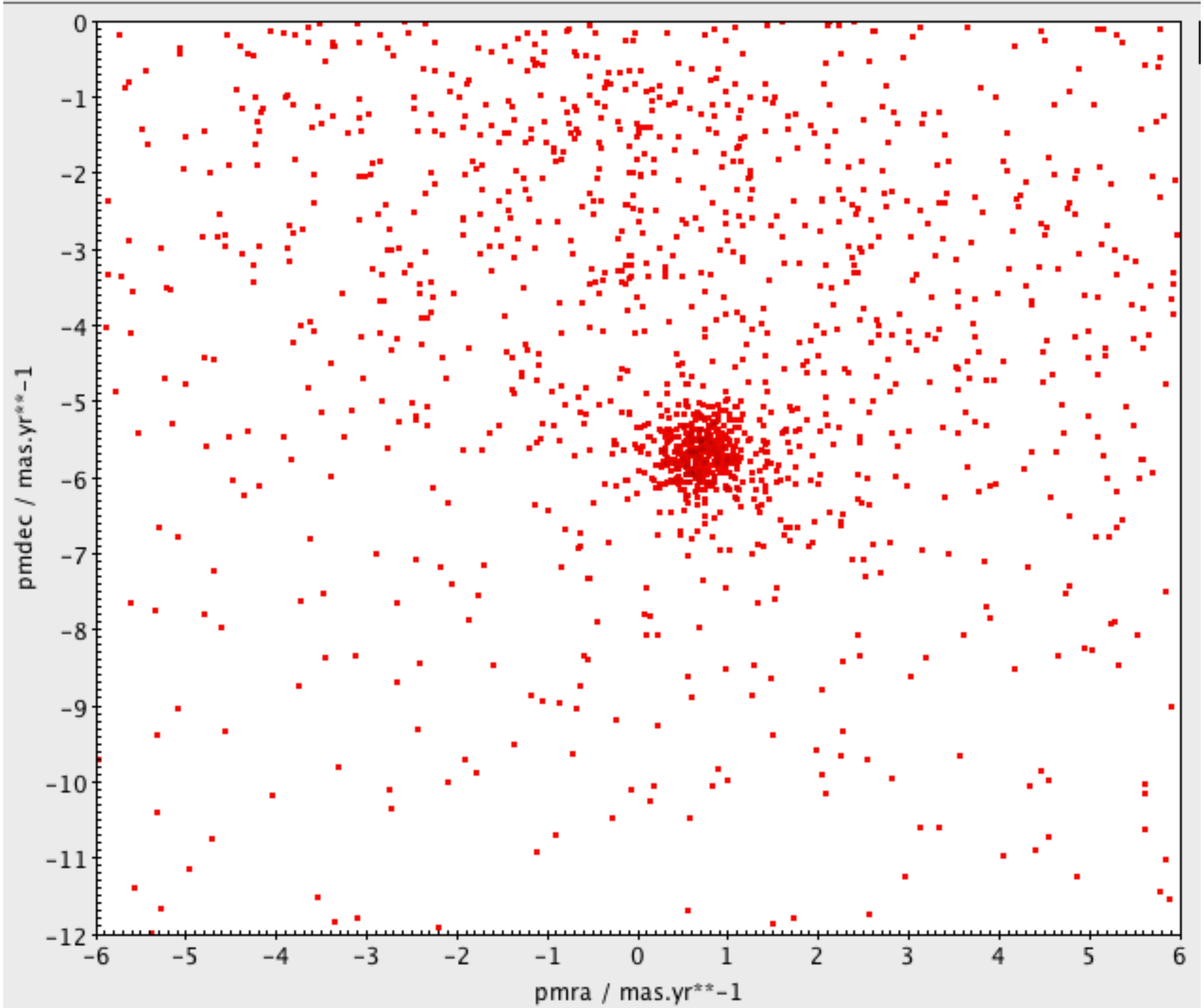


M34 CMD
WIYN 0.9m telescope
Green – proper motion member
Red – radial velocity member
Blue – photometric member

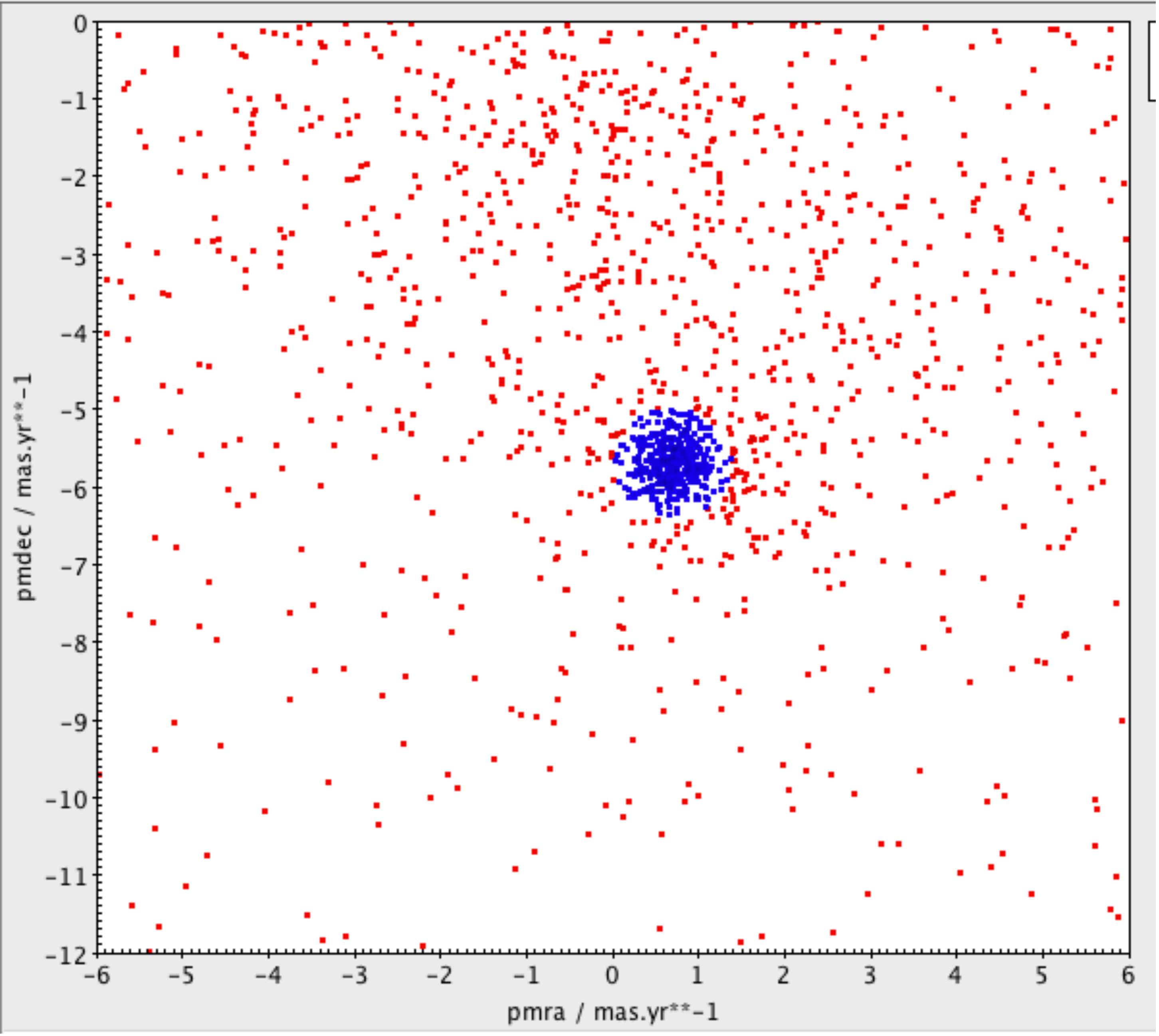
Meibom et al. 2011, ApJ, 733, 115



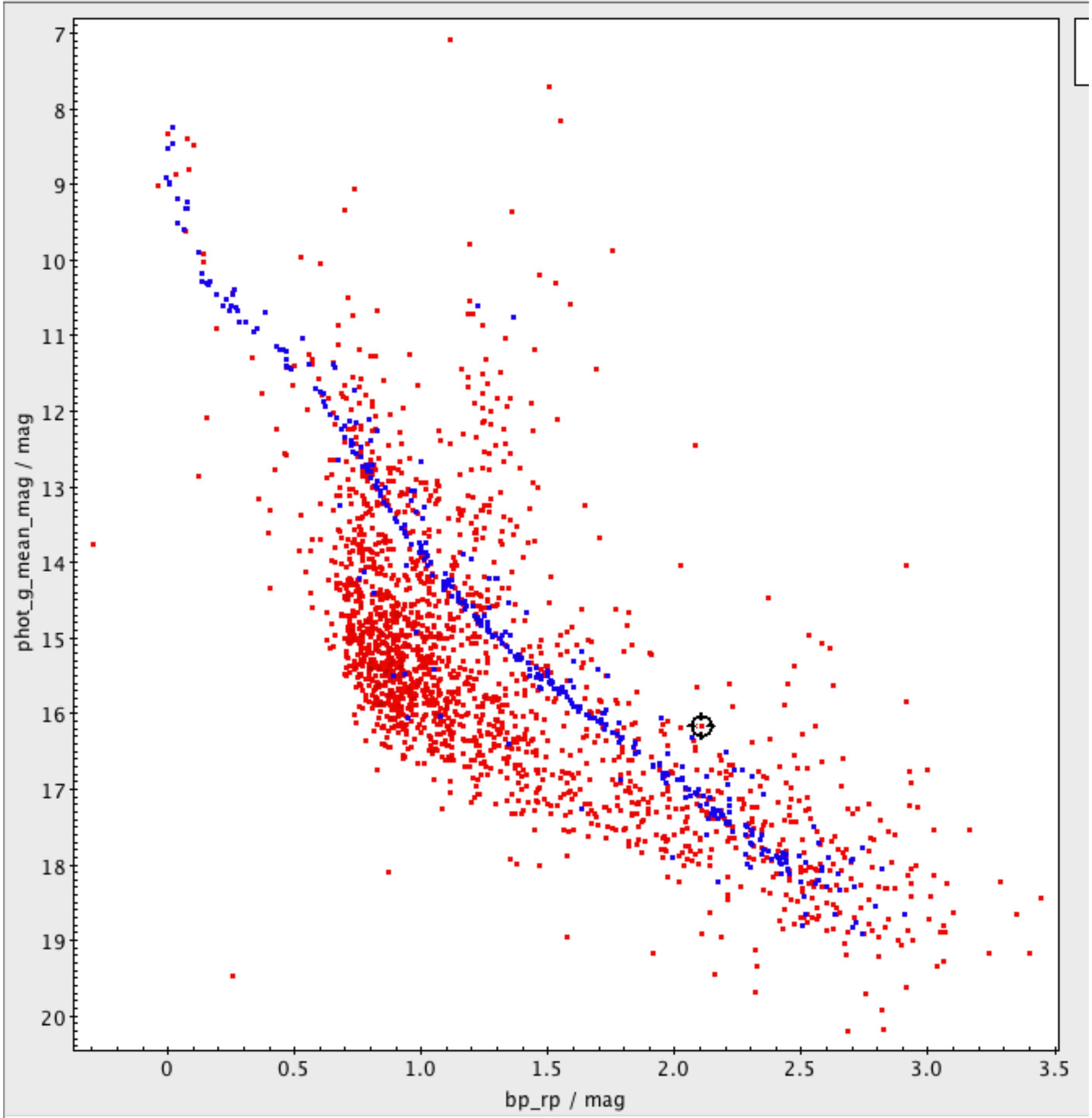
Gaia satellite data release 2 photometry. All stars within 0.5 degrees of the cluster center with parallax uncertainty < 10%.



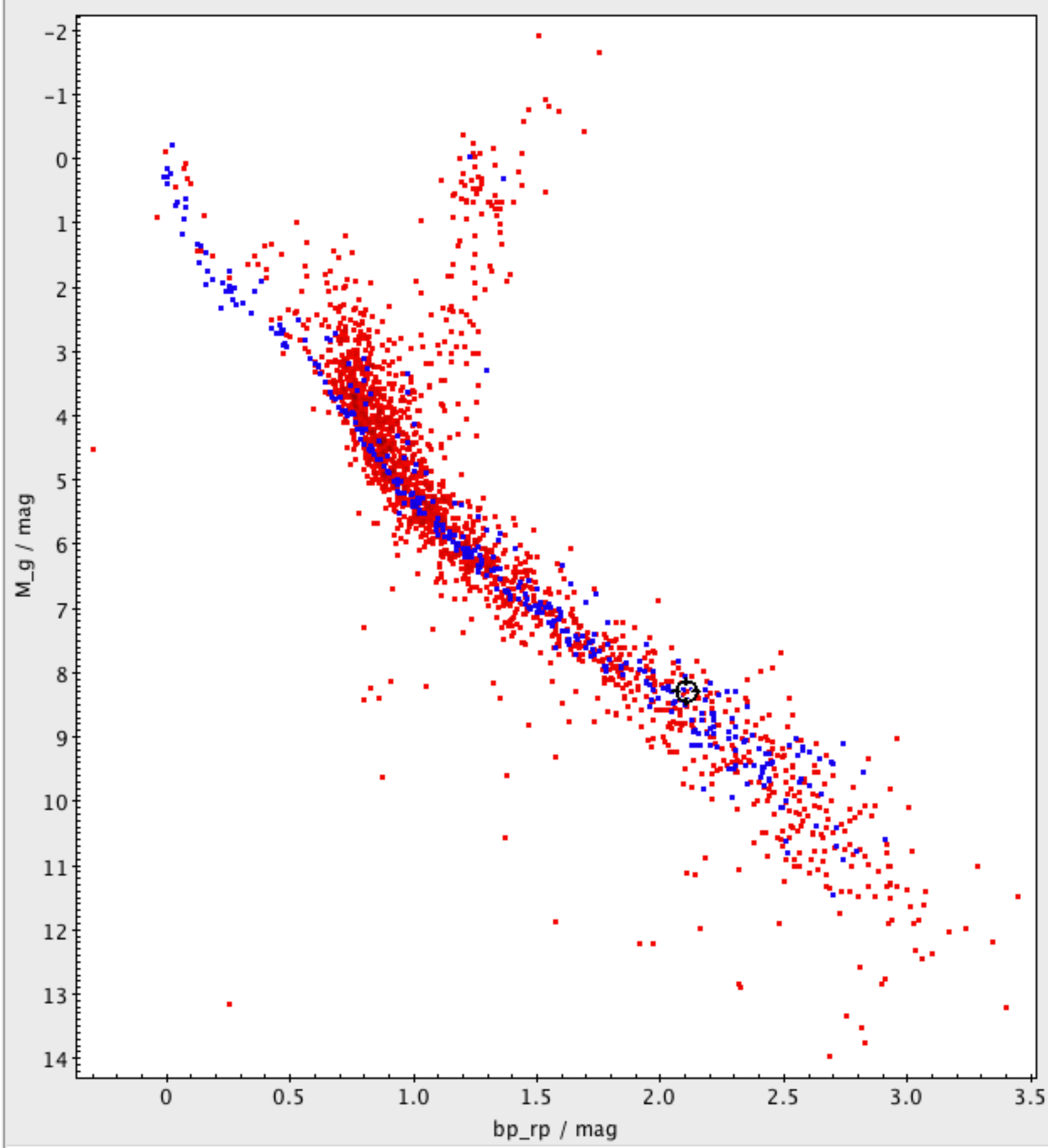
Gaia satellite data release proper motions. All stars within 0.5 degrees of the cluster center with parallax uncertainty < 10%.



Gaia satellite data release proper motions. All stars within 0.5 degrees of the cluster center with parallax uncertainty < 10%.



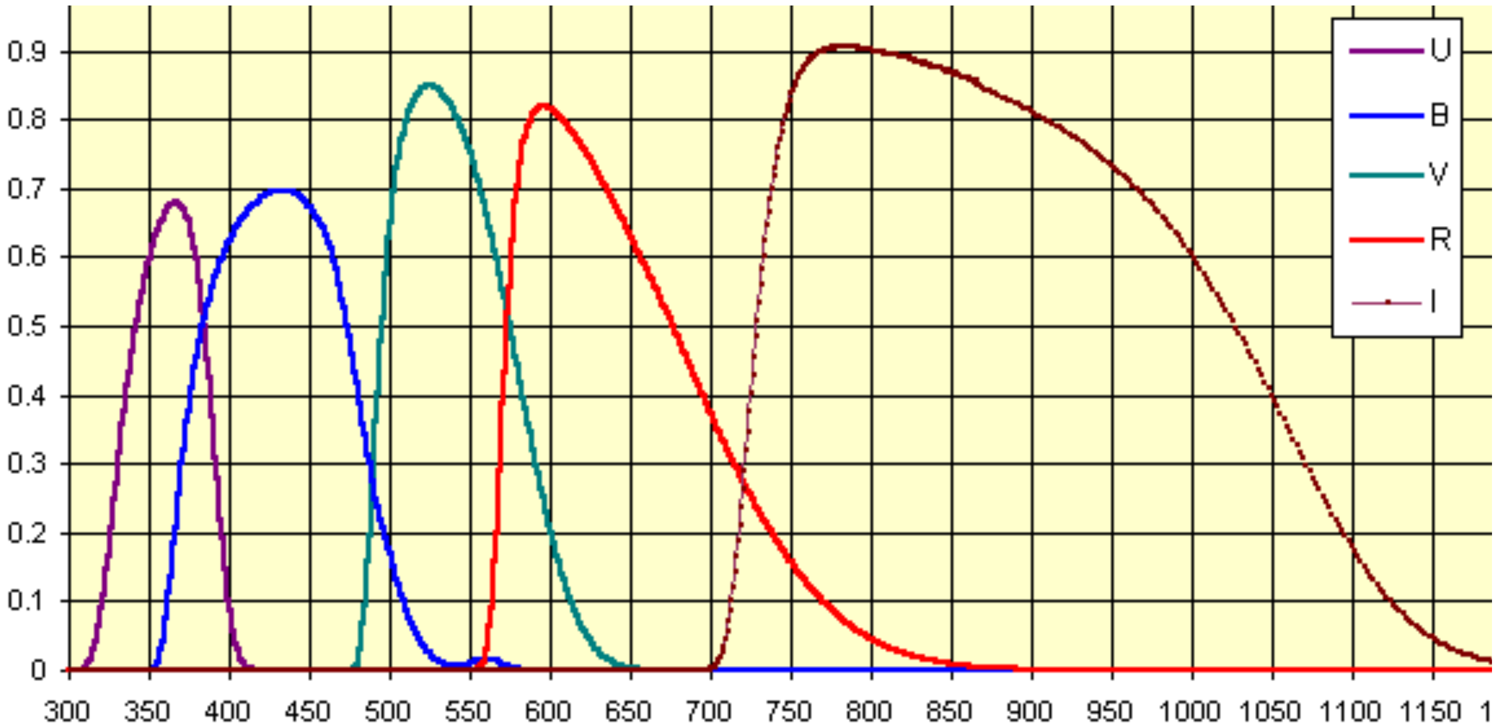
Gaia data release 2 photometry. All stars within 0.5 degrees of the cluster center with parallax uncertainty < 10%. Blue points are proper motion members.

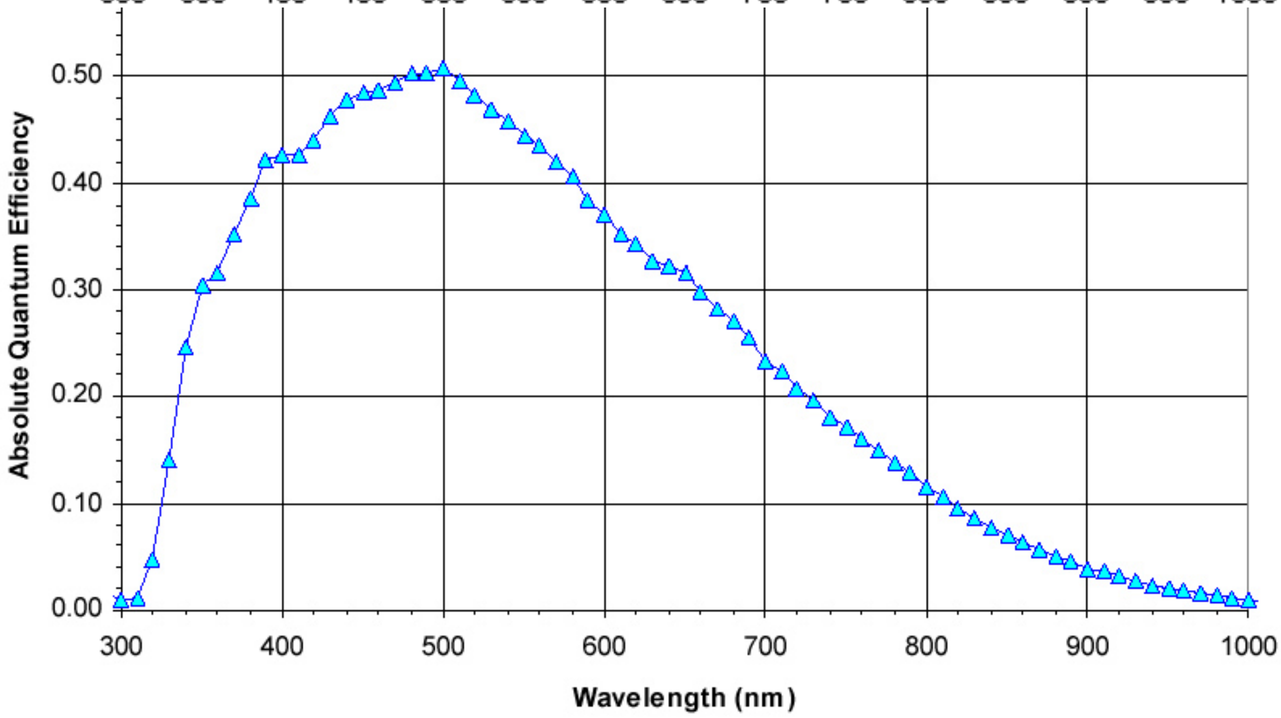


Gaia data release 2 photometry. Use proper motions to change g magnitude to absolute g magnitude. Blue points are proper motion members.

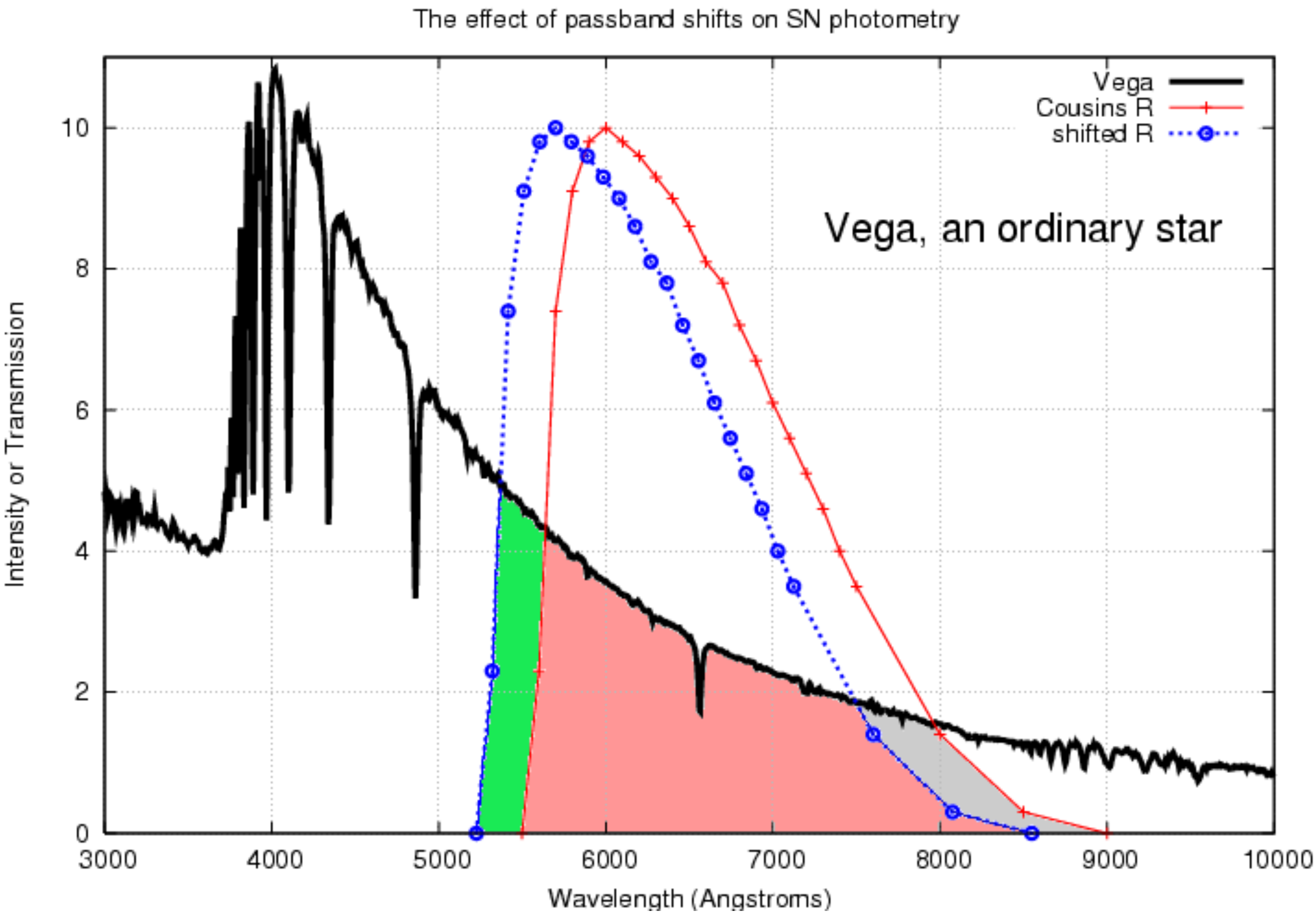
Transformation to Standard Magnitudes

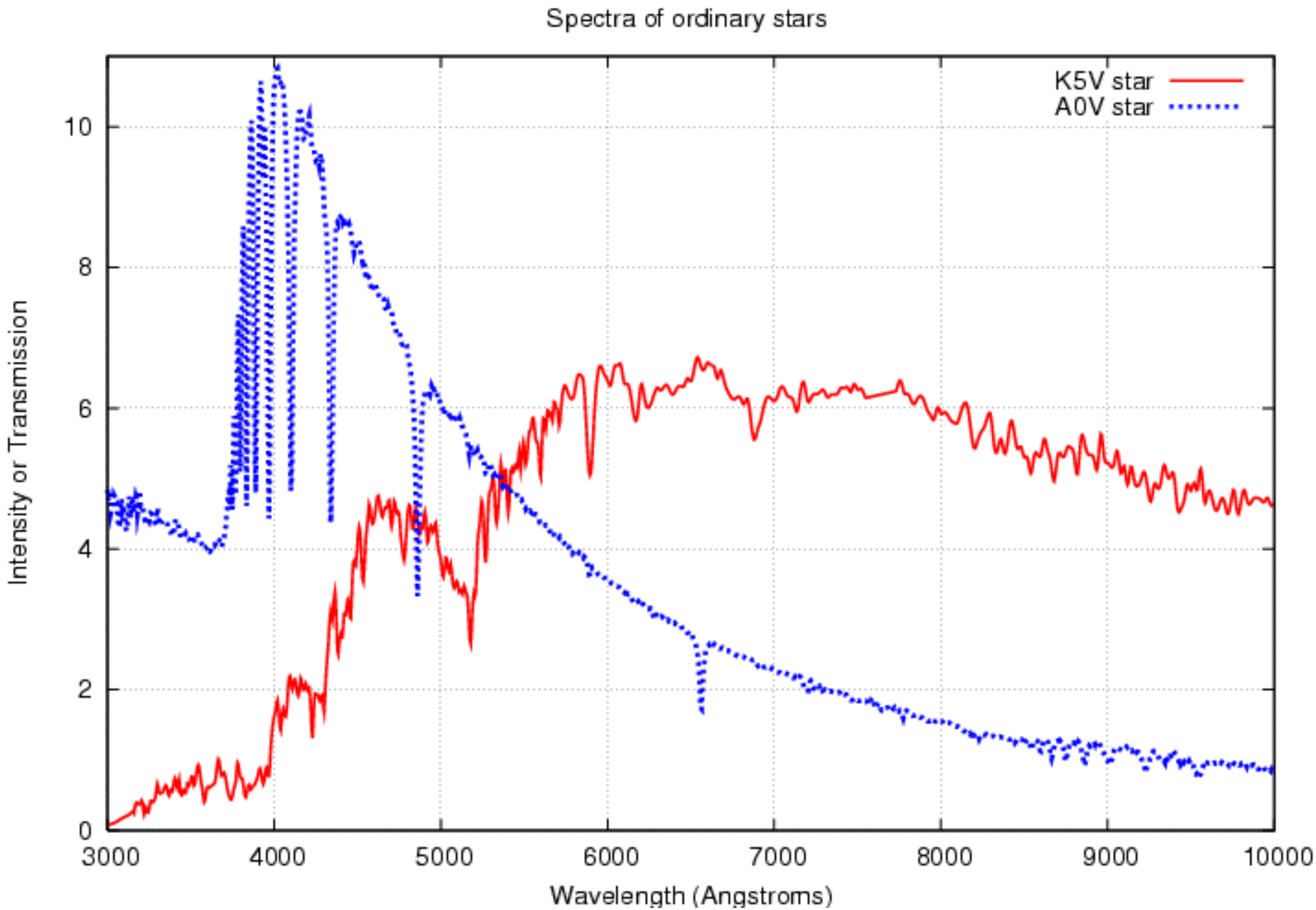
- The simplest transformation would be a simple additive correction, like that for atmospheric extinction, to account for the efficiency of the telescope and detector.
- However, the passbands defined by our filters and the spectral response of the CCD do not exactly match that of the standard system (which was defined by a 1P21 photomultiplier tube that is no longer made).
  - As the following figures illustrate, the shift in the passband causes the correction to depend on the temperature of the star.





The quantum efficiency of the CCD is varying significantly across the V and B bands.


The effect of passband shifts on SN photometry
Vega
Cousins R
shifted R
Vega, an ordinary star
Intensity or Transmission
Wavelength (Angstroms)
0
2
4
6
8
10
3000
4000
5000
6000
7000
8000
9000
10000



The effect of a shifted passband will be different for hot and cool stars.

Transformation to Standard Magnitudes

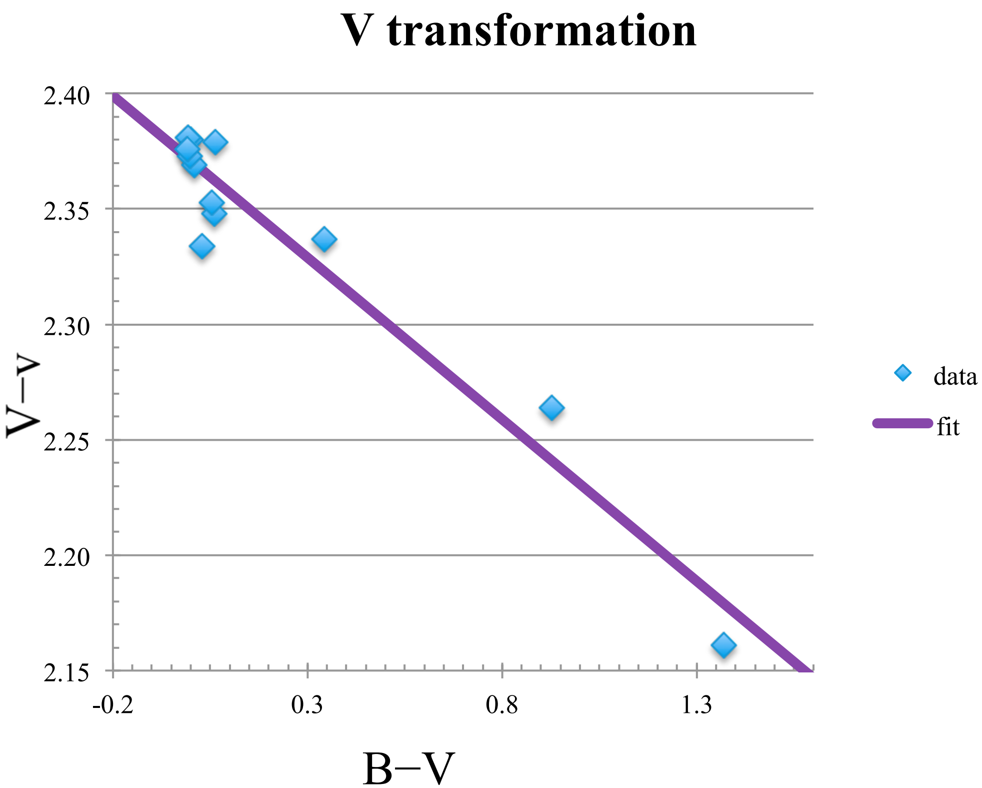
- Thus, the standard transformation equations are:
  - $B - V = \phi_{bv} + \mu_{bv} (b - v)$
  - $V - v = \phi_v + \varepsilon (B - V)$
  - Here, B and V are the standard magnitudes and b and v are the instrumental magnitudes.
  - These can be considered first-order Taylor expansions. We will ignore higher order terms (they are usually unimportant).
  - The μ_{bv} coefficient would be 1.0 and ε would be 0 if our system matched the standard one.
    - Actually differ from these values by 0.2 – 0.4.

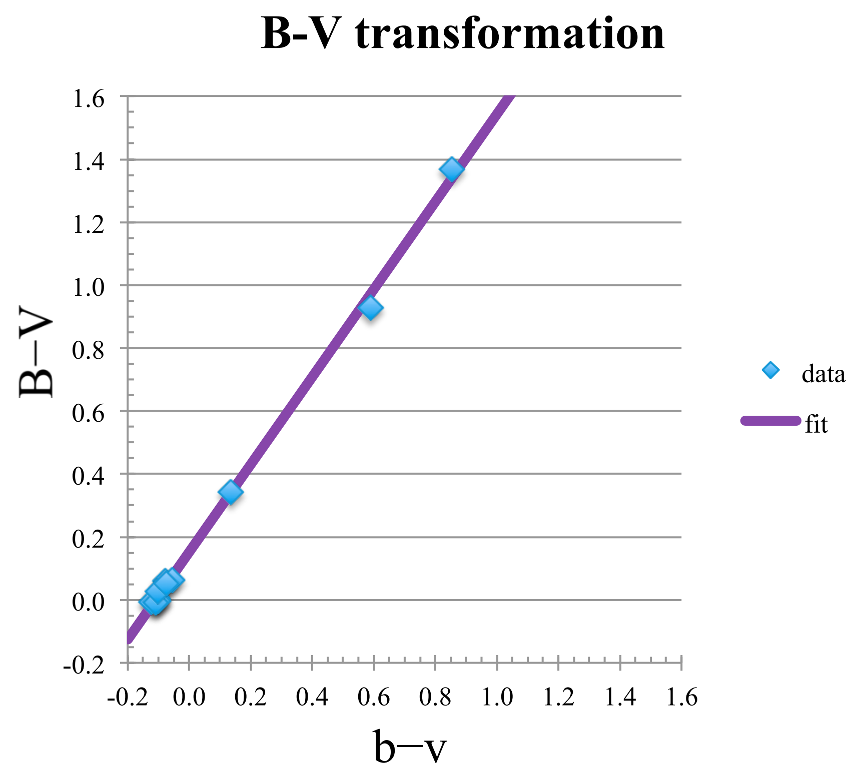
Fitting the Transformations

- B−V equation:
  - Calculate a column of $\Delta_{B\text{-}V} = (B-V) - (\phi_{bv} + \mu_{bv}\,(b - v))$
  - Make another column of $(\Delta_{B-V})^2$ and sum to form $\chi^2 = \Sigma_i\,(\Delta_{B-V,i})^2$.
  - Minimize χ^2 by varying ϕ_{bv} and μ_{bv} using solver in excel.
- V equation:
  - Calculate a column of $\Delta_V = V - (v + \phi_v + \varepsilon\,(B - V))$
  - Proceed as above to determine ϕ_v and ε.

	v0	unc v0	i0	unc i0	v0-i0	unc v0-i0	V	B-V	V-I	V-v0	V-v0-phi'_v-eps'*(V-I)		V-v0-phi'_v	V-I-phi_vi-mu_vi*(v-i)0	
sa92-312	10.3644	0.0011	10.4867	0.0008	-0.1223	0.0014	10.598	1.636	1.806	0.2336	0.0160	2.53547192	-0.1951	0.0054	0.28336973
sa92-309	13.4550	0.0069	14.8408	0.0130	-1.3858	0.0147	13.842	0.513	0.652	0.3870	0.0345	4.439005462	-0.0417	0.0127	0.51303391
sa93-322	12.3056	0.0037	13.7286	0.0058	-1.4230	0.0069	12.676	0.528	0.608	0.3704	0.0128	1.21588242	-0.0583	0.0030	0.05915716
sa92-276	11.7043	0.0033	12.9668	0.0011	-1.2625	0.0035	12.036	0.629	0.726	0.3317	-0.0121	1.445673742	-0.0969	-0.0266	6.30161005
sa92-282	12.5850	0.0026	14.2186	0.0049	-1.6336	0.0056	12.969	0.318	0.422	0.3840	0.0047	0.178115507	-0.0446	0.0105	0.84645438
sa92-364	11.3473	0.0035	12.6443	0.0017	-1.2970	0.0039	11.673	0.607	0.714	0.3257	-0.0195	3.683766134	-0.1029	-0.0069	0.41029304
sa92-288	11.3301	0.0007	12.4021	0.0014	-1.0720	0.0016	11.631	0.858	0.932	0.3009	-0.0189	3.489068225	-0.1278	0.0043	0.18351424
feige24	11.9727	0.0044	13.6094	0.0096	-1.6367	0.0106	12.412	-0.203	0.444	0.4393	0.0625	20.33706995	0.0106	0.0353	5.90615511
feige24A	13.4726	0.0168	14.8719	0.0303	-1.3993	0.0346	13.822	0.525	0.635	0.3494	-0.0051	0.025212103	-0.0793	0.0081	0.05087156
feige24B	13.1844	0.0130	14.4893	0.0211	-1.3049	0.0248	13.546	0.668	0.749	0.3616	0.0205	0.767454991	-0.0671	0.0354	1.75097248
feige24C	11.4954	0.0029	12.3297	0.0032	-0.8343	0.0043	11.761	1.133	1.127	0.2656	-0.0314	8.927991238	-0.1631	-0.0192	3.10685731
												47.04471169			19.412289
phi_v	0.412	epsilon	-0.115												
phi'_v	0.429	epsilon'	-0.117					-0.4	0	0.4286					
phi_vi	1.913	mu_vi	0.919					1.8	2	0.1949					

Transformations





The smaller range of b-v compared to B-V may arise because the CCD quantum efficiency weights our B band towards long λ's and our V band towards short λ's, thus reducing our wavelength baseline (hence, sensitivity to T).

Interstellar Extinction & Reddening

- Caused by scattering from "dust" grains in the interstellar medium.
  - About 1 magnitude of dimming per kiloparsec of distance in the plane of the Galaxy.
  - A major headache.
- Scattering cross-section is larger at shorter wavelengths (Rayleigh scattering), so light is reddened.

Interstellar Extinction & Reddening

- Dust grains properties uniform, so there is a (nearly) universal relation between reddening and extinction.
  - Reddening: $E(B-V) = (B-V) - (B-V)_0$
  - Extinction: $A_V = V - V_0 = 3.1\ E(B-V)$

- Reddening is not easy to determine.
  - Measure spectral type of stars and use relation between color and type for very nearby stars.
- For Lab 6 you are given E(B-V) and use it to correct your photometry to V_0 and $(B-V)_0$.

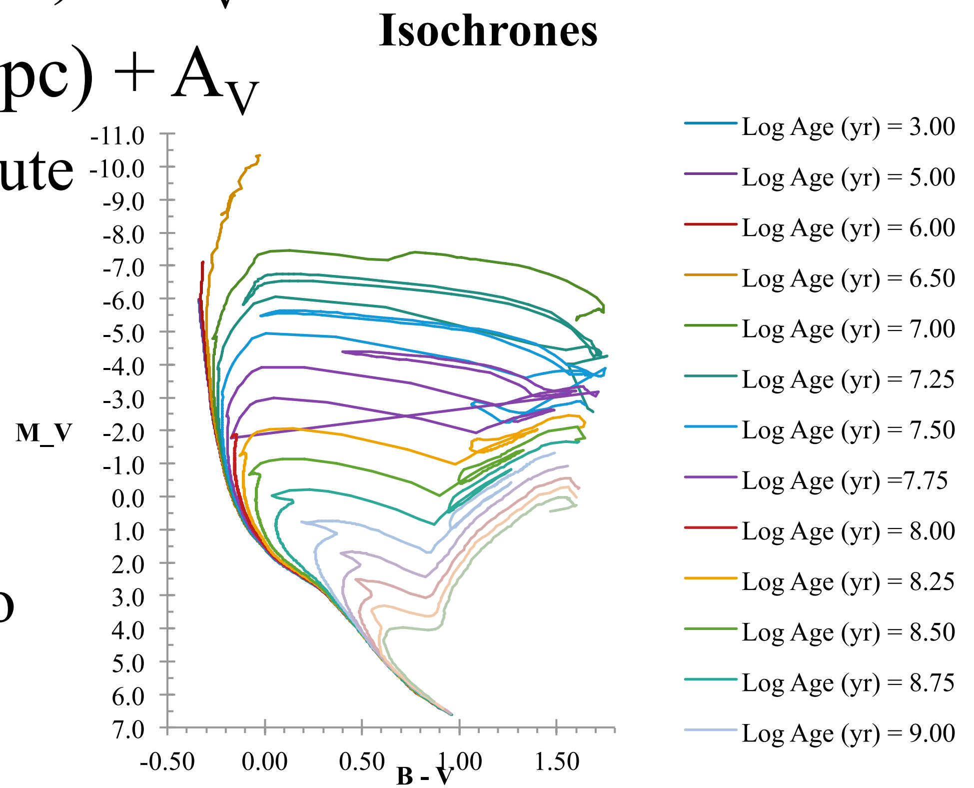
Cluster Distance

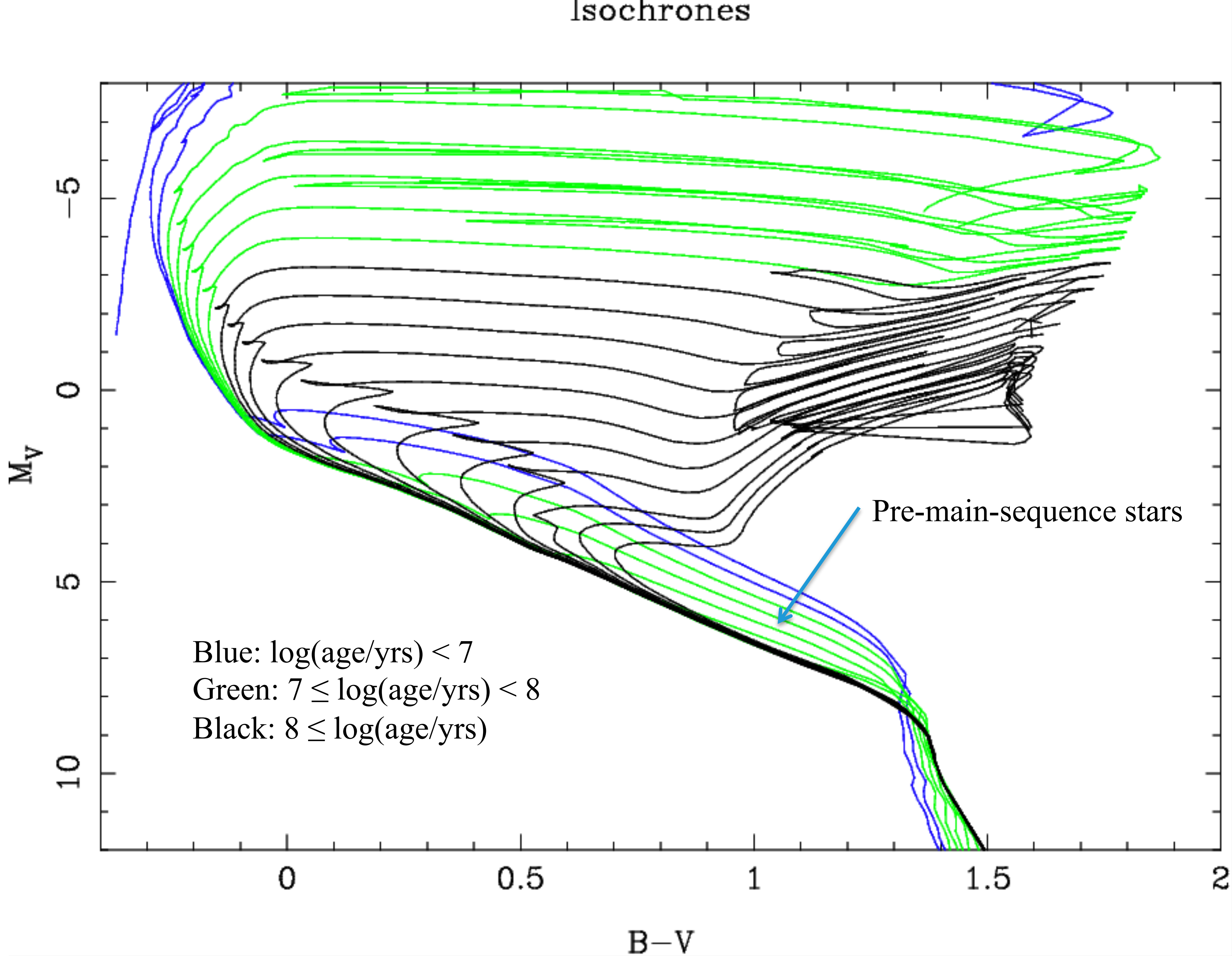
- Slide a theoretical "zero-age" main sequence isochrone vertically until it matches the cluster main sequence.

$$m - M = 5 \log(d/10\ \text{pc}) + A_V$$

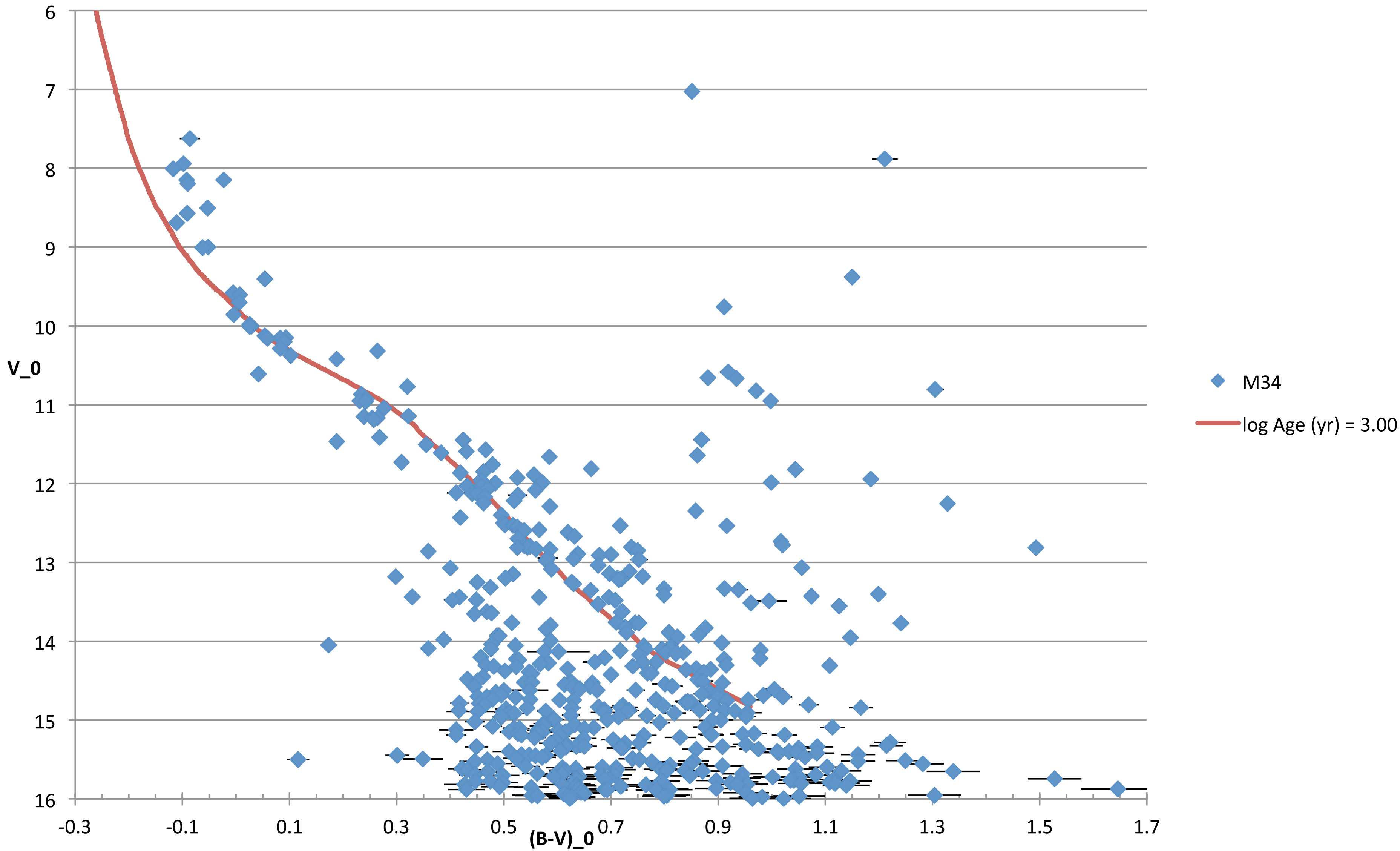
$$m = M_V + 5 \log(d/10\text{pc}) + A_V$$

  - M_V = isochrone absolute magnitudes
  - m = shifted isochrone apparent magnitudes
  - d = cluster distance
  - A_V = extinction due to interstellar dus.

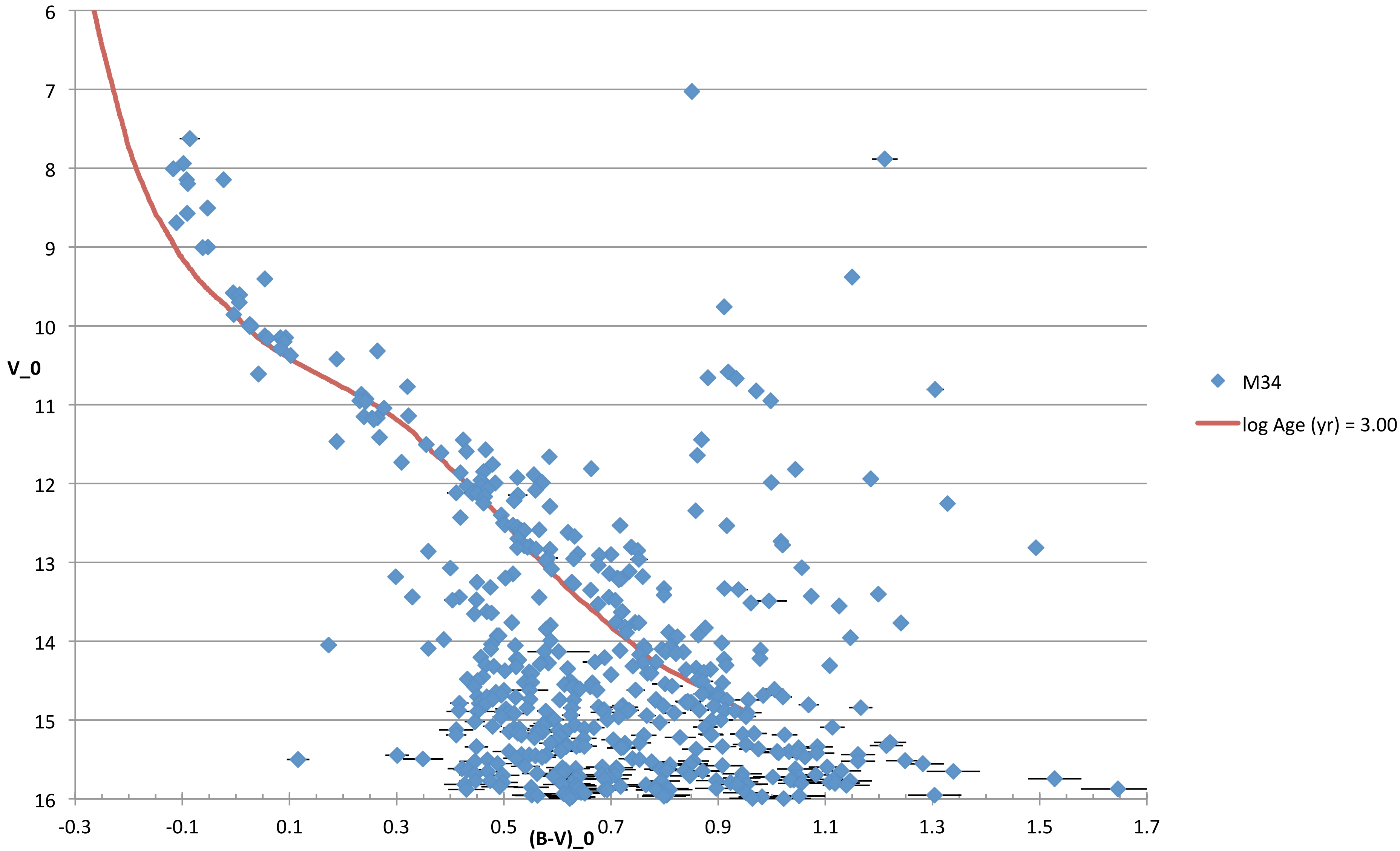



Isochrones
−5
0
5
10
M_V
0
0.5
1
1.5
2
B−V
Pre-main-sequence stars
Blue: log(age/yrs) < 7
Green: 7 ≤ log(age/yrs) < 8
Black: 8 ≤ log(age/yrs)

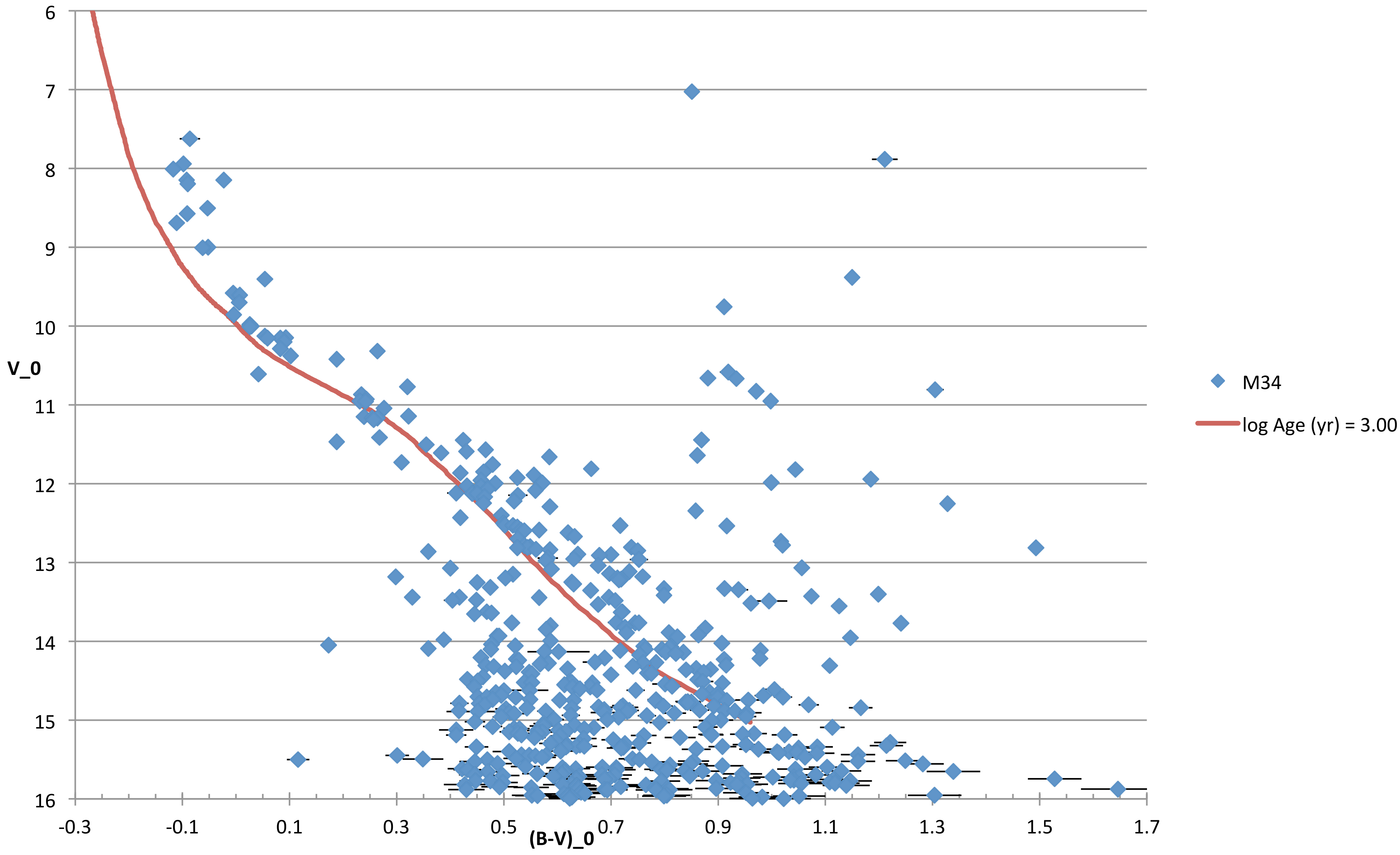
Increasing the m−M adopted for the isochrone in steps of 0.1.



Increasing the m−M adopted for the isochrone in steps of 0.1.

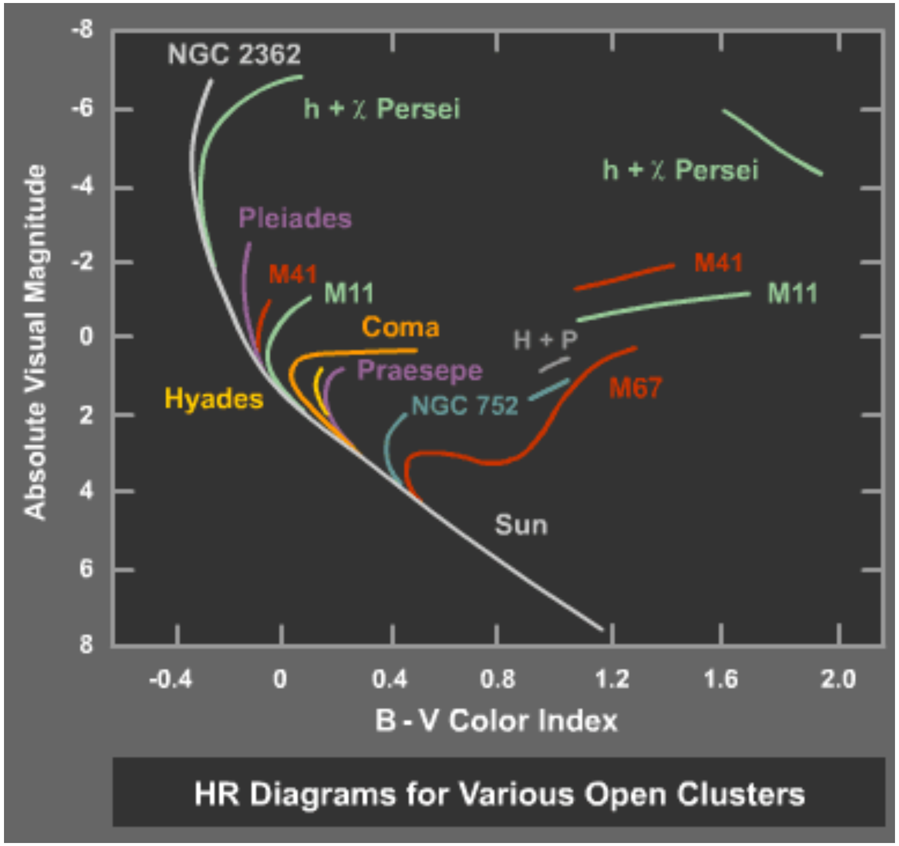


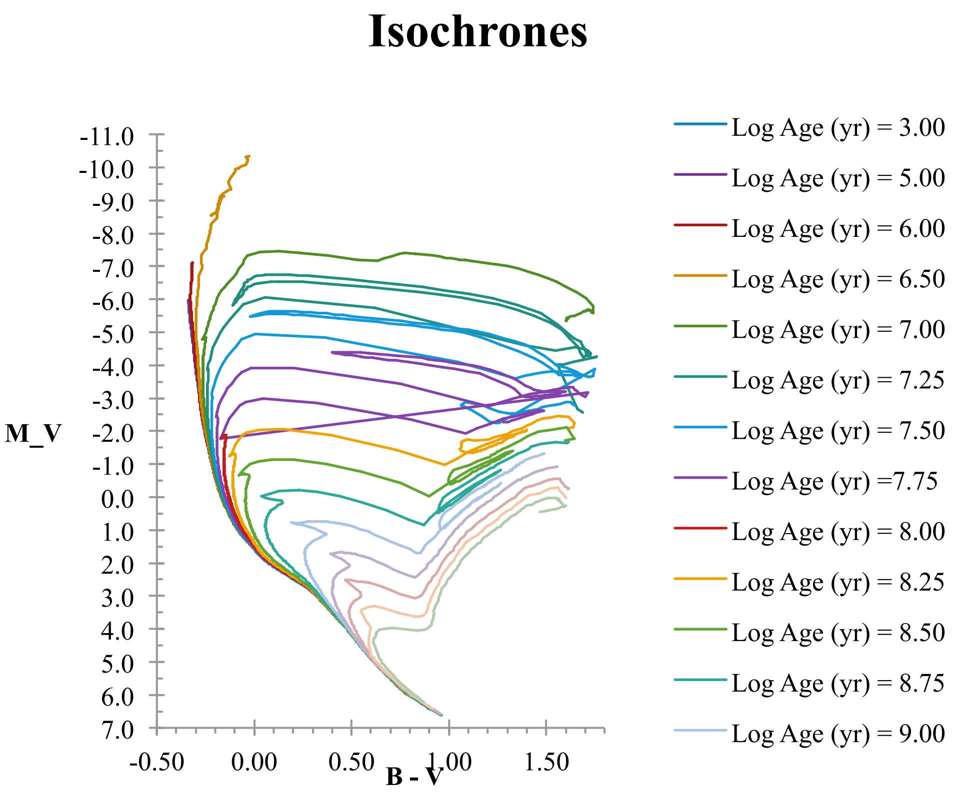
Increasing the m−M adopted for the isochrone in steps of 0.1.



Cluster Age

- Match the main-sequence turnoff.





Isochrones with different ages and best (m−M)